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Heat Transfer of Alumina Sands in Fluidized Bed Combustor with Novel Circular Edge Segments Air Distributor

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Abstract

Fluidized bed combustor, which consists of a reaction chamber, an air distribution plate, uses inert particles, as its bed material. In order to ensure stable operation, it is apparent that the operating velocity of the air should be sufficiently large so that the flow rate through it is relatively undisturbed by the bed pressure fluctuation above it. However, high distributor pressure drop in fluidized bed system is undesirable because it will lead to high energy input in the blower to supply the fluidization air to fluidize the inert sand particles. Thus, the new novel designs of air distributor that consists of circular edge segments that contributed to low pressure drop and improvement of heat and mass transfer in fluidized bed combustor is introduced and will become primary interest of this research. The effects of temperature variations between an electrically heated tube immersed vertically in fluidized bed and alumina particles of various sizes were experimentally studied. In this paper, the data for heat transfer coefficient for an electrically heated vertical tube immersed vertically in fluidized bed combustor consists of alumina particles diameter ranging from ($\bar{d}_p$= 100, 177 and 250 μm) is reported at temperature from 50 °C to 250 °C.

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Keywords: Fluidized bed combustor; Heat transfer; Circular edge segments air distributor;

1. Introduction

High heat transfer coefficients and uniform temperatures are major reasons why fluidized beds are widely used in many commercial applications such as chemical production, drying, coating, roasting. Research on heat transfer in fluidized beds has been carried out for several decades, and the mechanism of heat transfer is generally well established for bubbling and fast fluidized beds. However, little work has been done to understand the mechanism of heat transfer in the transition region between bubbling and fast fluidization, known as turbulent fluidization. It was Geldart. D [1] who first categorized the behavior of particle fluidized by gases falls into four clearly recognizable groups A, B, C, D, characterized by density

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Nomenclature

A	surface area, m^2
$\bar{d}$	mean diameter, m
g	acceleration of gravity, m/s^2
H	height, m
h	heat transfer coefficient, W/m^2K
I	electric current, A
Q	heat flow rate from heater to bed, W
T	Temperature, ^oC
U	air velocity, m/s
V	electrical potential difference, V
W	weight of the bed, kg

Greek symbols

ΔP	pressure drop, N/m^2
ε	bed voidage, [-]
μ	viscosity, $N.s/m^2$
ρ	density, kg/m^3

Subscripts

b	bed
f	fluid
p	particles
s	solid
t	heater tube
pc	particle convective
gc	gas convective
rad	radiation

difference and mean particle size. Thus, many commercial units operated by using particles classification of Geldart group A or B. [2], [3] The mechanism of heat transfer between a bed and immersed heat transfer surface under condition of conventional fluidization consist of three additive components, including the particle convective component, the interphase gas convective component, h_{gc} and the radiant component of heat transfer h_{rad} [4].

$$h_{overall} = h_{pc} + h_{gc} + h_{rad} \tag{1}$$

The particle convective component, h_{pc}, is depend upon heat transferred by particle circulation between the bulk of the bed and the region directly adjacent to the heat transfer surface. The interphase gas convective component, h_{gc}, contributes to the process of heat transfer by convective mixing which augments the heat transfer in the gas gaps between the particles and the heat transfer surface and between neighboring particles. The radiant component of heat transfer, however, becomes significant only for the bed operates at temperature above 700 °C.

A wide range of designs exist for the type of distributor plates used in fluidized beds [5]–[10]. The main three types are: (i) porous plate, (ii) multi-orifice distributors and, (iii) sparge pipe designs. The most important functional requirements are to create uniform fluidization and to ensure combustion. However, in most cases this is tied in with a requirement for low pressure losses in operation. In addition, the distributor design must allow for good thermal behavior and possible particle flowback. In a fluidized bed combustor where low pressure losses are essential, a shallow bed is required and multi-orifice distributor is then the best type. In this paper, the data for heat transfer coefficient for an electrically heated vertical tube immersed vertically in bubbling fluidized bed contains alumina particles belonged to group A and B of Geldart classification with mean diameter ($\bar{d}_p$= 100, 177 and 250 μm) is reported at temperature ranging from 50 ^oC to 250 ^oC.

2. Experimental setup

2.1 Classification of Alumina sands

The physical properties of the particles used in the experiment are tabulated in Table 1. The average diameter of particles, $\bar{d}_p$ is obtained from the sieve analysis of solid particles using the following relation

$$\bar{d}_p = \frac{1}{\Sigma_i\left(\frac{w}{d_p}\right)_i} \quad (2)$$

Particle classifications were done based on the work of Geldart D. [1] who first categorized the behavior of particle into four clearly recognizable groups: A, B, C and D based on particle density difference and mean particle size $\bar{d}_p$.

Table 1. Properties of alumina particles.

$\bar{d}_p$ (μm)	Particle density ρ_s (kg/m^3)	Geldart Classification
100	2342	Group A
177	2099	Group B
250	2009	Group B

2.2 Fluidized bed set up

The experiments were conducted in the Energy and Sustainability Focus Group Laboratory in Faculty of Mechanical Engineering, University Malaysia Pahang by using a laboratory scale cylindrical glass column of 108 mm internal diameter and 260 mm long as shown in the Fig. 1.

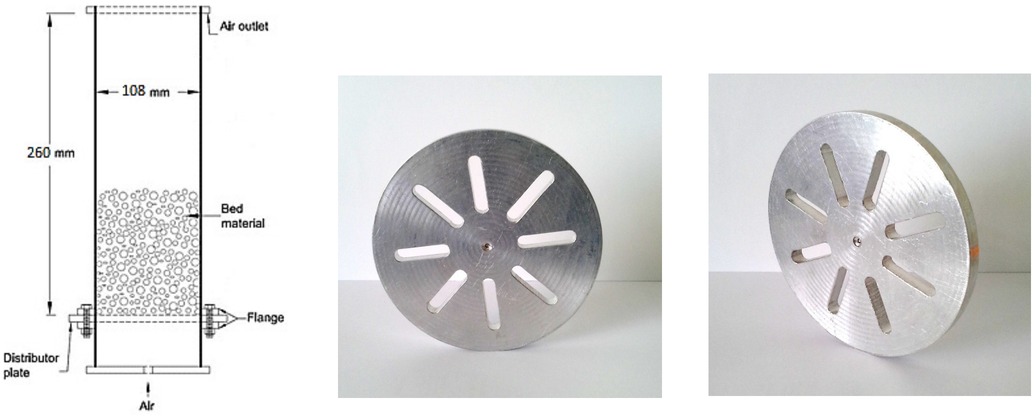

Fig. 1. Schematics of the fluidized bed and novel circular edge segments air distributor

A centrifugal compressor supplies the fluidizing air at ambient conditions to the system and an orifice meter provides the measurement of air flow rate into the system.115 mm diameter circular segmented-type air distributor plate of thickness 8 mm made of aluminium was used in the experiments. The 8 segments with 6mm diameter circular edged openings was used giving open area ratio of 3%. The static bed height in all experiments is kept the same at 40 mm and is measured by a strip of scale tape located on the outside of the glass cylinder.

The sands is heated by SMATEC™, 800 W electrically heated copper tube, fitted with a T-type thermocouple and mounted vertically 25 mm above the distributor, capable of heating up the bed up to 400 °C. The ends of the tube are provided with Teflon support to reduce axial heat loss, which is estimated to be less than 1%. A DC power supply with a voltage regulation of 0.1% is used to energize the heater. A voltmeter and an ammeter with an accuracy of 0.5% are used to measure the electric power supplied to the heater. To measure bed and ambient temperature, two T-type thermocouples were located at the bulk of the bed and the outlet of the column respectively. The temperatures of the thermocouples were recorded simultaneously during the operation, via a computer controlled temperature measurement system. Data were logged via 32-channel expansion board and analog-digital converter to a PC. The temperature and pressure data were recorded for a 15 minutes period with a 1 second sampling time. Due to the short length of the tube, the temperature was assumed uniform along the axial length of the surface, and the amount of average heat transfer coefficient was determined by using the equation

$$h = \frac{Q}{A_t(T_t - T_b)} \quad (3)$$

4. Results and discussions

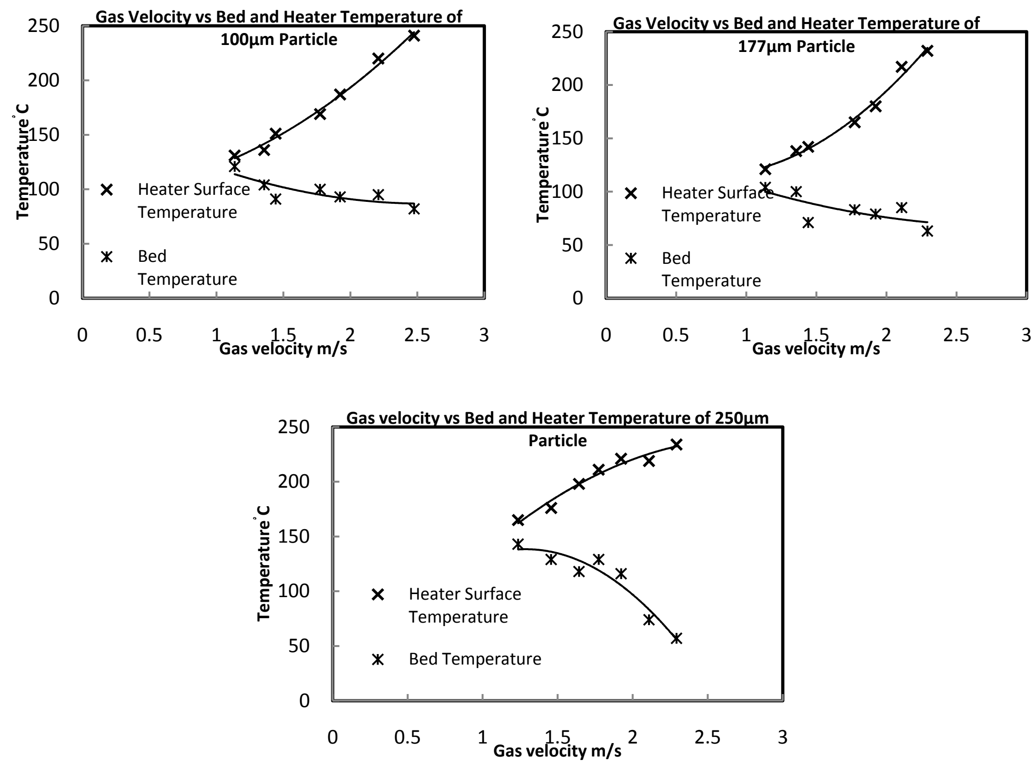

Fig. 2. Bed and heater temperature as a function of gas velocity for 100 µm, 177 µm and 250 µm particles.

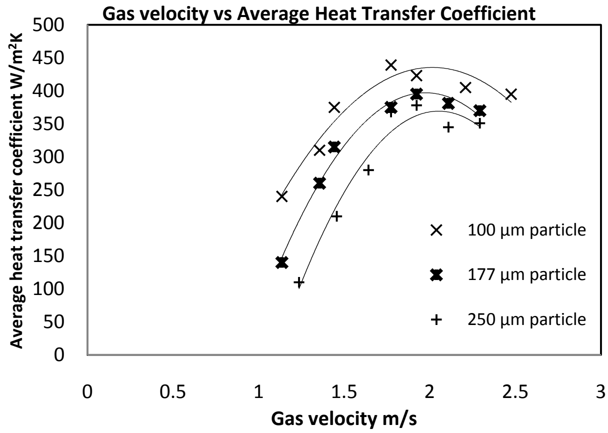

Fig. 3. Effect of gas velocity on the average heat transfer coefficient for 100 µm, 177 µm and 250 µm particles.

The temperature profiles of bed and immersed heater surface in fluidized bed chamber were plotted in Figs. 2 for temperature ranging from 50 ºC to 250 ºC. The temperature profiles for heater surface are fairly uniform at all operations as a result of constant increment of voltage to energize the heater except for the bed operating with 250 µm particles where a small decrement of temperature gradient is observed at higher operating temperature. The temperature profiles of bed, however, seem to be rather uniform and characterized by small temperature gradient for the bed operating with 100 µm and 177 µm particles respectively. Fig. 3. shows the value of the average heat transfer coefficient as a function of gas fluidizing velocity, for sand particles of diameter 100, 177 and 250 µm respectively. The qualitative variation of the dependence of heat transfer coefficient on gas velocity is in agreement with reported trends observed by previous investigators [11]–[16] in which, the heat transfer coefficient increases with the increase in value of gas velocity. The heat transfer coefficient attains a maximum value at the excess optimum fluidizing velocity. With further increase in velocity, the value of heat transfer coefficient decreases. Whereas an increase in operating pressure as the fluidizing gas velocity is progressively increased i.e. when the gas flow conditions are in the transitional or turbulent flow regime could be expected to lead to some reduction in the overall heat transfer coefficient because of a possible increase in continuous phase voidage and hence reduction in particle packing density at the heat transfer surface.

For a new distributor plate design, the plate with an extended opening area to the peripheral of the bed was found to be effective at enhancing the circulation rate. Particle circulation was observed to increase linearly with an increase in gas velocities. The circulation rate was observed to slightly increase with the decrease in particle size. The trend is reported the same with the published work of [17]. The effect of pressure drop across the circular edge segments air distributor is actually the integrated effect of the geometric parameters on fluidization quality.

Conclusions

The effects of temperature variations between an electrically heated tube immersed vertically in fluidized bed and sand particles of various sizes were experimentally studied. The average heat transfer coefficient increases with increasing gas velocity towards a maximum value of the coefficient. An increase in operating pressure as the fluidizing gas velocity is progressively increased could be expected to lead to reduction in the overall heat transfer coefficient because of a possible increase in continuous phase voidage and hence reduction in particle packing density at the heat transfer surface. The result also shows that the value of maximum heat transfer coefficient decreases with increase in particle diameter due to increase in gas conduction path and decreases in particle surface area per unit volume for heat exchange with the heater surface. For future work, it is recommended that the scope of the present study be expended to diverse heat transfer surface and bed geometries. It can be concluded that bigger ratio of distributor pressure drop over bed pressure drop $\Delta P_d/\Delta P_b$ values will result in more complete fluidization. But the air blower consumes more energy at higher distributor pressure drops and, thus, a balanced consideration must be taken when choosing the proper air distributor.

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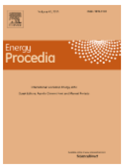

Biography

Ahmmad Shukrie joins Universiti Malaysia Pahang (UMP) in 2012 as a research fellow in Energy and Sustainability Focus Group, Faculty of Mechanical Engineering and currently pursuing his PhD in Mechanical Engineering at the same university. His primary research interests are in the field of fluidization, fluid flow, heat transfer and tidal energy conversion.